EFFECT OF INITIAL AND EXHAUST PRESSURES OF THE ECONOMY OF A SIMPLE HIGH-SPEED ENGINE

BY

A. H. GREENSPAHN

ARMOUR INSTITUTE OF TECHNOLOGY

1919

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The Effect of Initial and Exhaust Pressures of the Economy of a Simple High-Speed Engine

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A THESIS

PRESENTED BY

ALLAN H. GREENSPAHN

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

MAY 29, 1919

APPROVED

G. F. Gebhardt
Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

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OBJECT:

The object of this thesis is to show the effect of initial and back pressures on the economy of a simple high speed engine, when running at various loads and at constant speed.

APPARATUS:

The engine used in making this experiment is an 8½" x 10" simple horizontal engine with a rating of 30 H.P. manufactured by the Phoenix Iron Works Company, of Meadville, Pa.

The steam is supplied to the engine through a 2" pipe and exhausts through a 3" pipe into a surface condenser. The piping layout is as shown in figure 7. The valve, which is of the piston type is as shown in figures 8 and 9, takes steam on the ends and exhausts in the center.

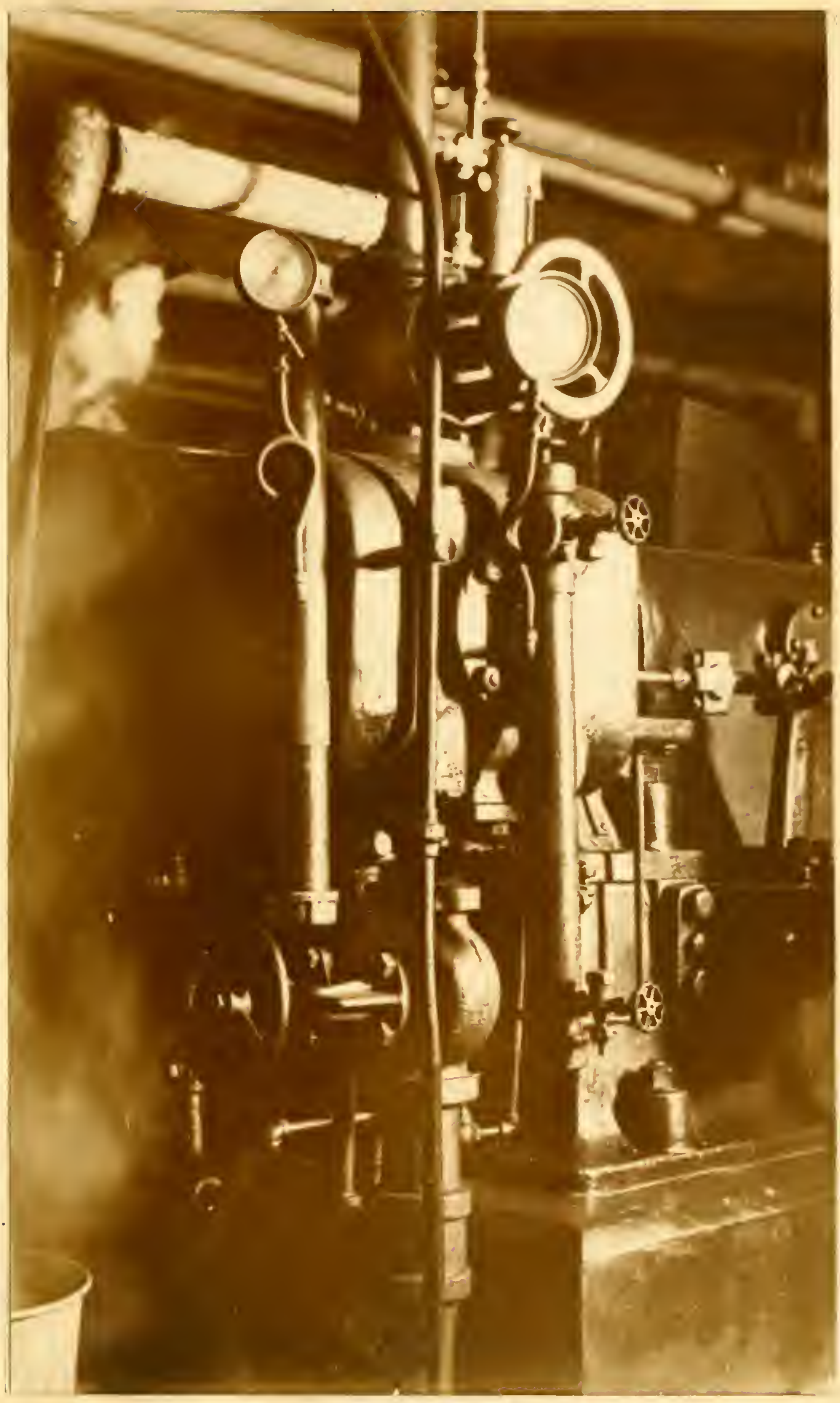
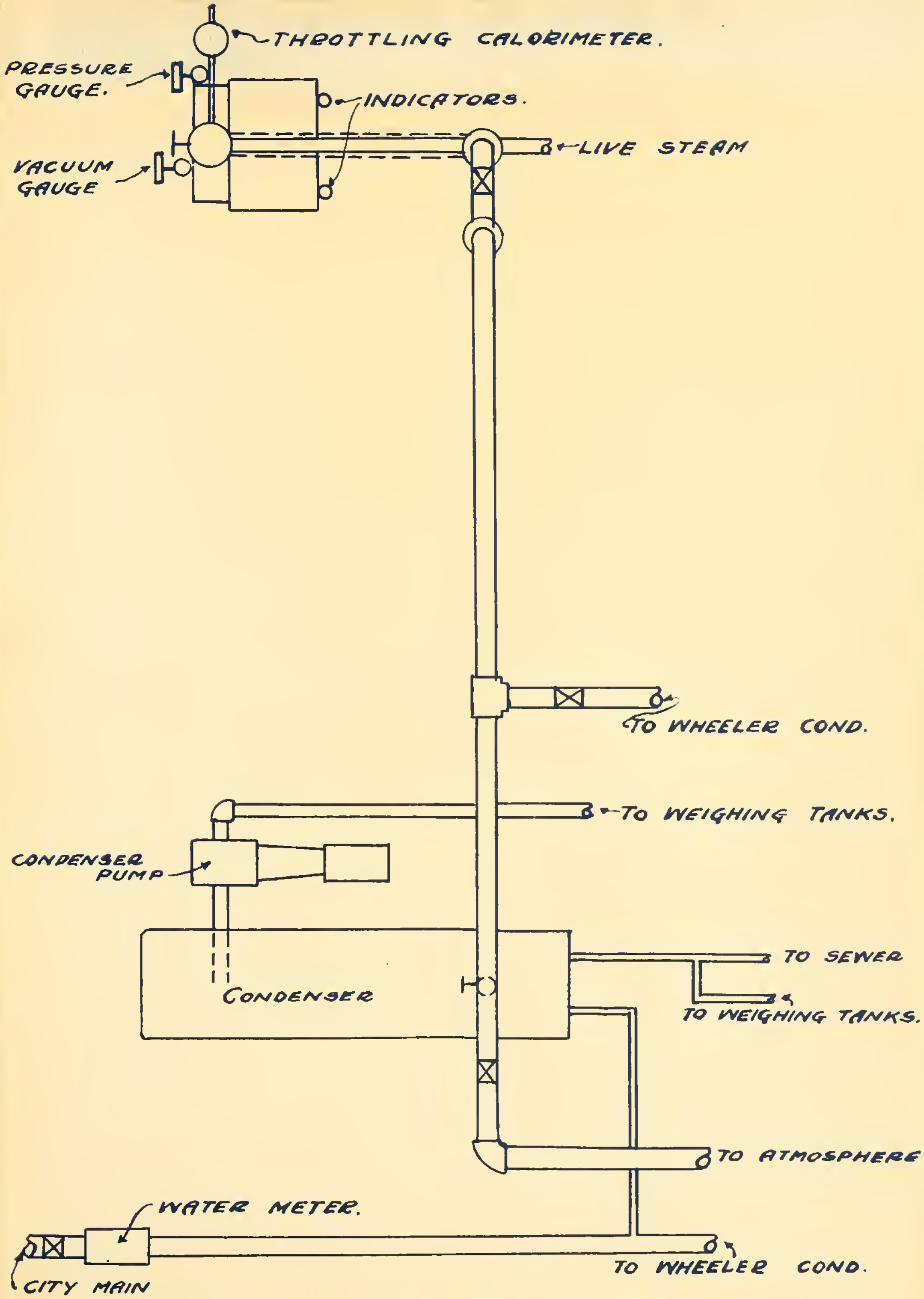


FIGURE 1.



PIPE DIAGRAM FOR PHOENIX STEAM ENGINE.

FIGURE 7.

The valve is operated by a shaft governor. This engine is of the self oiling type having oil recesses cast in the frame so that at each revolution oil is thrown by the ceank, thereby oiling all the bearings.

The auxiliary apparatus consists of Crosby Indicators, for obtaining the indicated Horse power; a throttling calorimeter, for obtaining the quality of the steam; steam and vacuum gauges, for obtaining the steam and vacuum pressures; a calorimeter thermometer, for obtaining the temperature in the calorimeter; tanks and scales, for obtaining the weight of condensed steam; and a prony brake, for applying the required load.

METHOD OF PROCEDURE:

Before starting this experiment the engine and its equipment were examined, in order that a better understanding of their

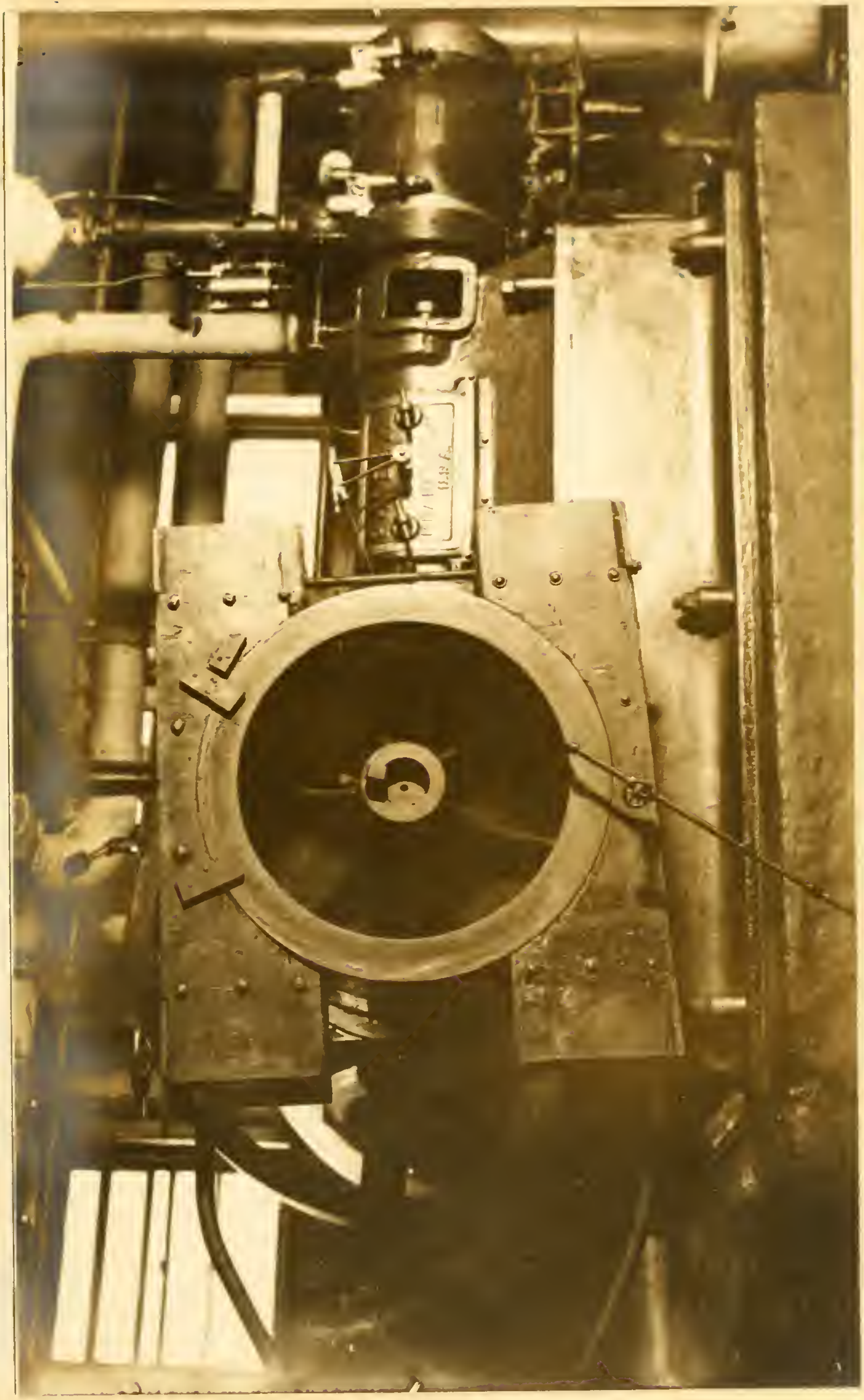
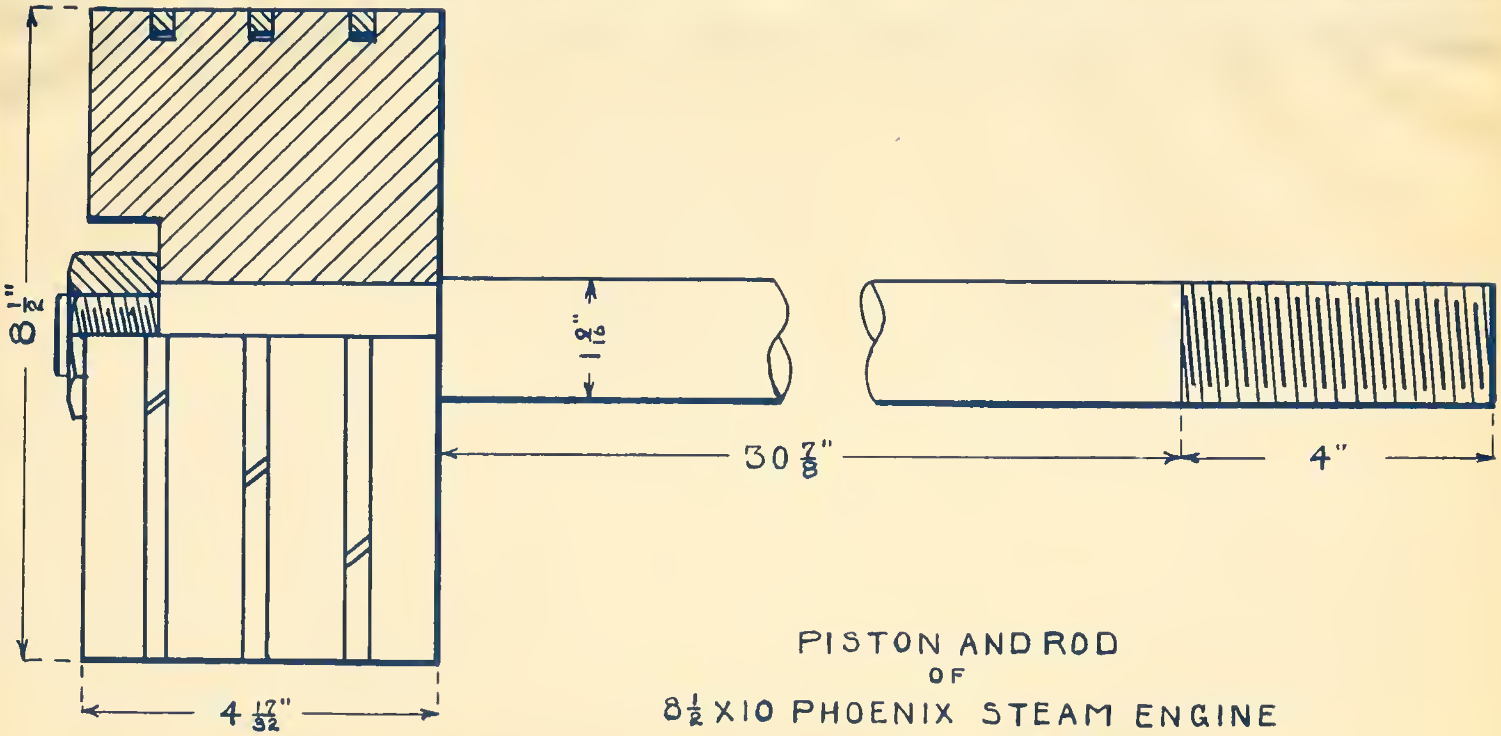


FIGURE 2.



PISTON AND ROD
OF
8 1/2 X 10 PHOENIX STEAM ENGINE
WEIGHT 59 LBS.

FIGURE 8.

operation might be ascertained. It was found that the engine had not been used for more than three years. For this reason the gland was removed from the stuffing box and the old packing removed. New packing was inserted and the gland replaced. The valve rod was also repacked. The grease cups were removed, cleaned and refilled. The crank case was drained, cleaned and then refilled with new oil.

In order to get correct pressures when reading the pressure gauges, it was found that it would be of better advantage to construct constant pressure reservoirs, consisting of a piece of iron piping 2 feet long and 2 inches in diameter, capped at both ends. Two of these were constructed each having $\frac{1}{4}$ inch pipe taps about 12 inches apart. The reservoirs were fastened to the cylinder head of the engine by means of 1/16 inch strap iron, as is shown in figure 1. One of these reservoirs was connected

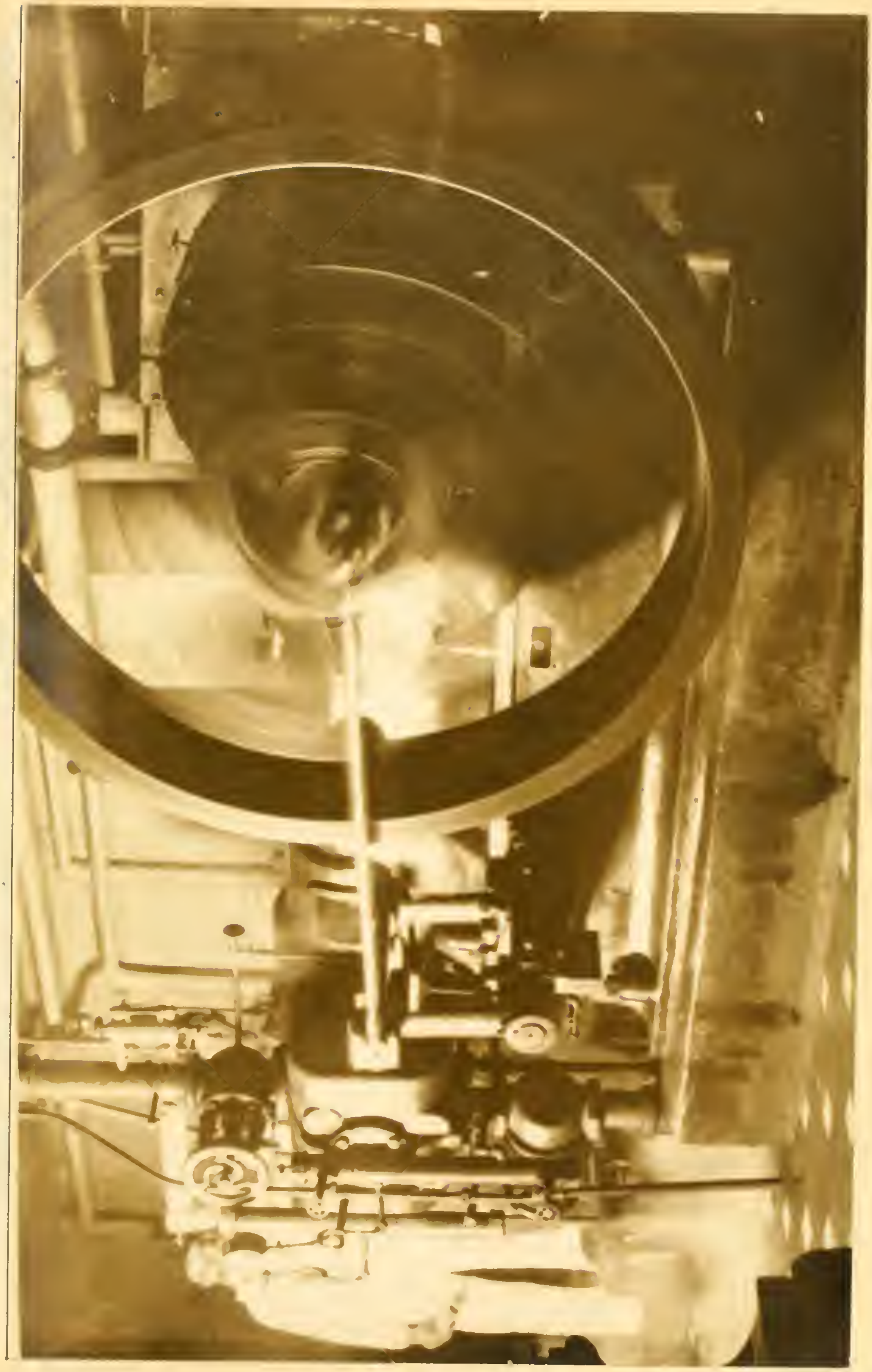
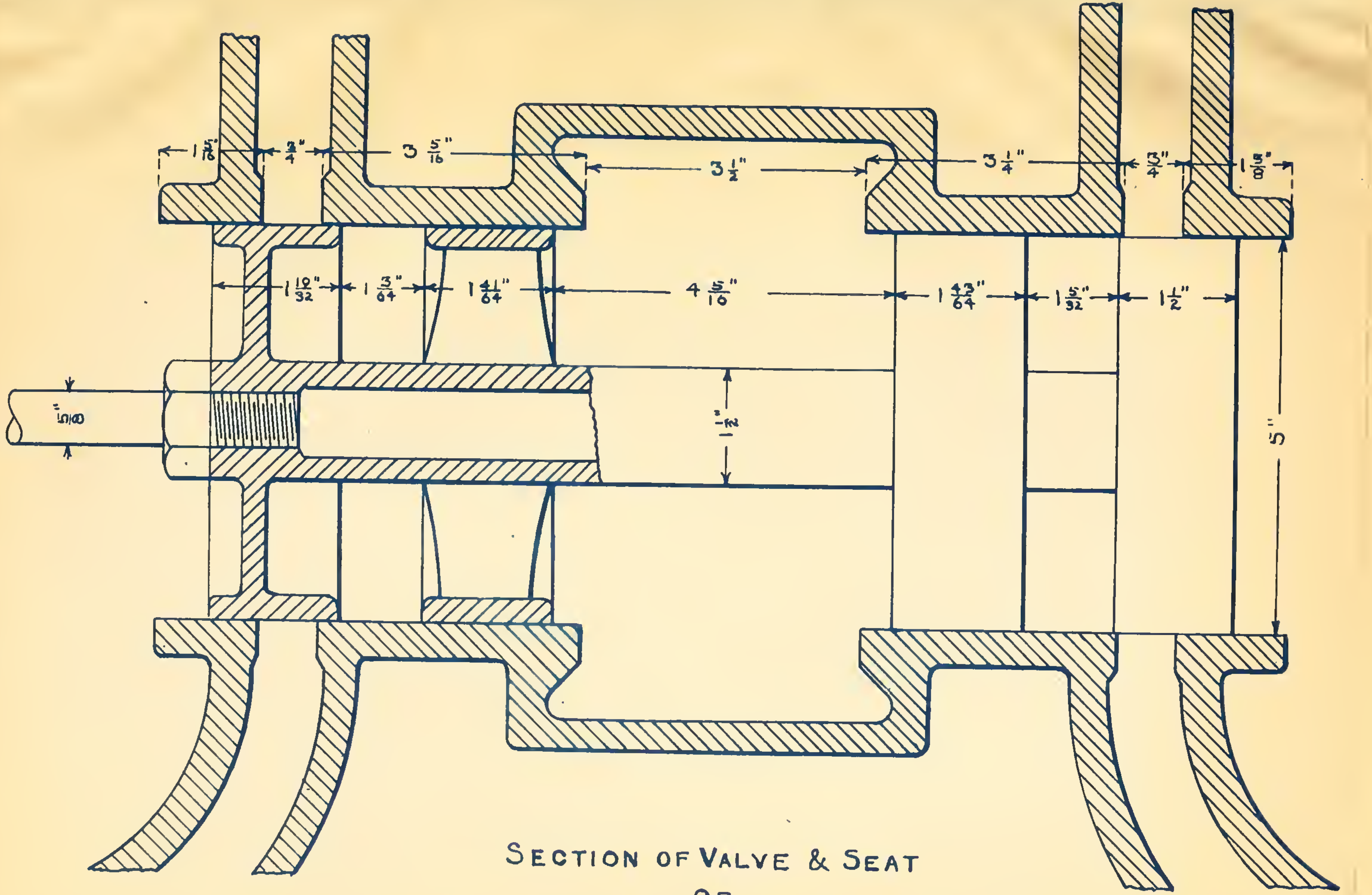


FIGURE 3.



SECTION OF VALVE & SEAT
OF
PHOENIX STEAM ENGINE

FIGURE 9.

to the steam line and the other to the exhaust line. "Goose-neck" pieces of $\frac{1}{4}$ inch piping were connected to the outlets and the pressure gauges attached as is shown in figures 1 and 3. Figure 1 shows the calorimeter in place. Figures 4, 5, and 6 show other views of this engine.

It was found necessary to calibrate the Fairbanks Standard Scale, before the weight of the unbalanced part of the Prony brake was determined. United States Standard 50 pound weights were placed upon the weighing platform and the zero point adjusted.

Two cross pieces as shown in figure 10, were constructed in order that the weight of the unbalanced portion of the Prony brake could be found. These consisted of two pieces of wood, $3\frac{1}{4}$" x 2'-6" x $\frac{3}{4}$" nailed together at right angles.

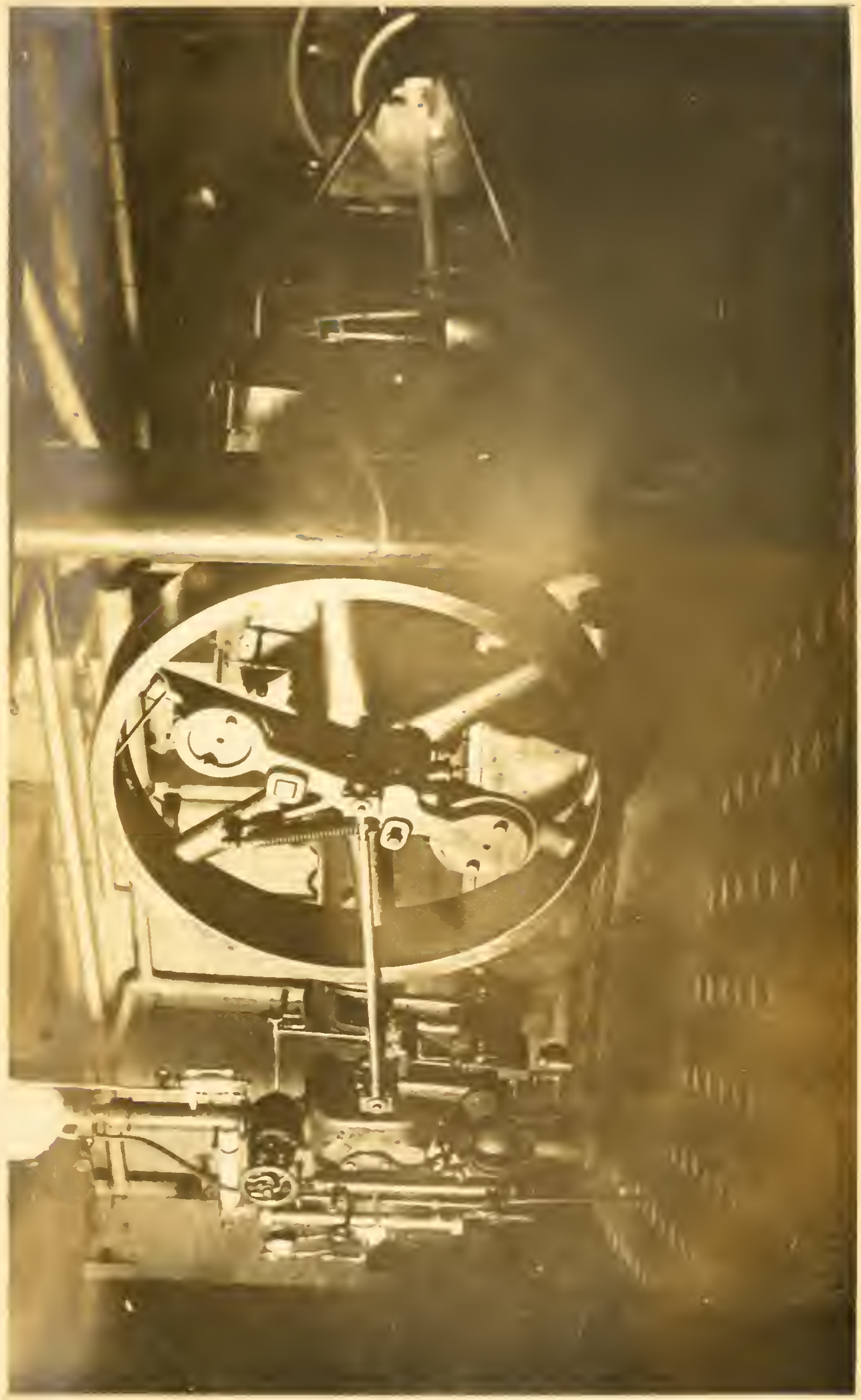


FIGURE 4.

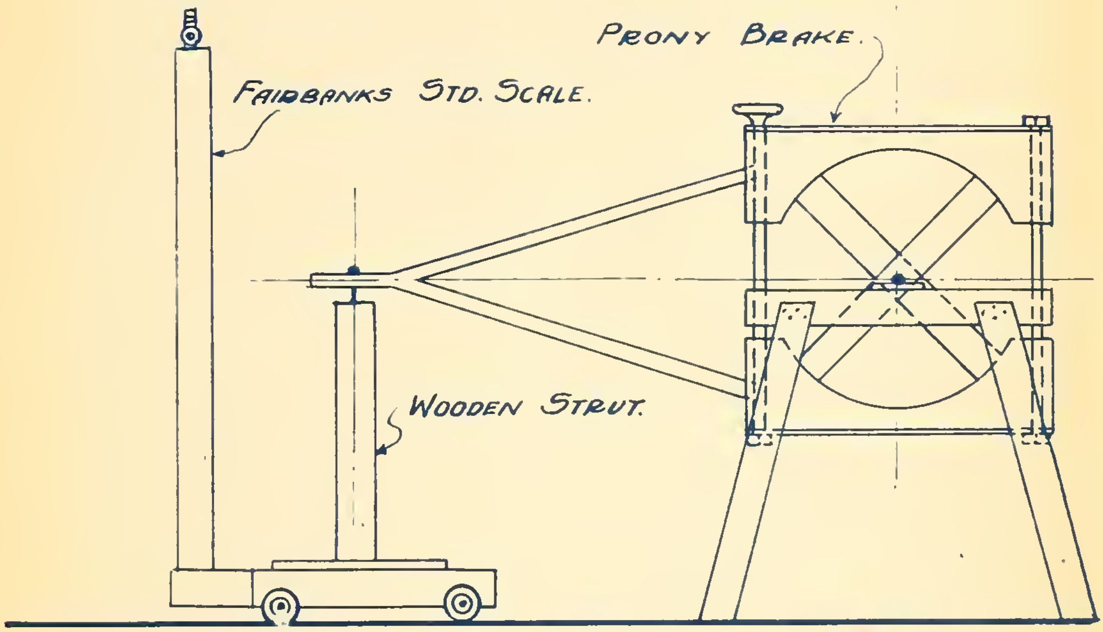


DIAGRAM SHOWING METHOD USED FOR FINDING WEIGHT OF UNBALANCED PORTION OF PRONY BRAKE.

—SCALE - $\frac{1}{2}''$ = 1'-0".—

GROSS WEIGHT ON SCALES - 22.0 LBS.
WEIGHT OF STRUT - 10.0 "
NET WEIGHT ON SCALE - 12.0 "

FIGURE 10.

A 7/8" hole was drilled through both pieces. The Prony brake was removed from the pulley wheel and laid upon the floor. The cross-pieces were then placed in a position, so as to take the place of the pulley; and a rod, 7/8 of an inch in diameter inserted through the holes in the cross-pieces.

The Prony brake was clamped and the apparatus was then lifted into place on knife edges upon wooden horses, the arrangement is as shown in figure 10. The total weight on scales was found to be 22 pounds, the weight of the wooden strut 10 pounds. This gave a net weight of 12 pounds for the unbalanced portion of the Prony brake.

Suitable means for piping the water used to cool the Prony brake and for the surplus water were made. The engine parts were thoroughly cleaned and the prony brake replaced

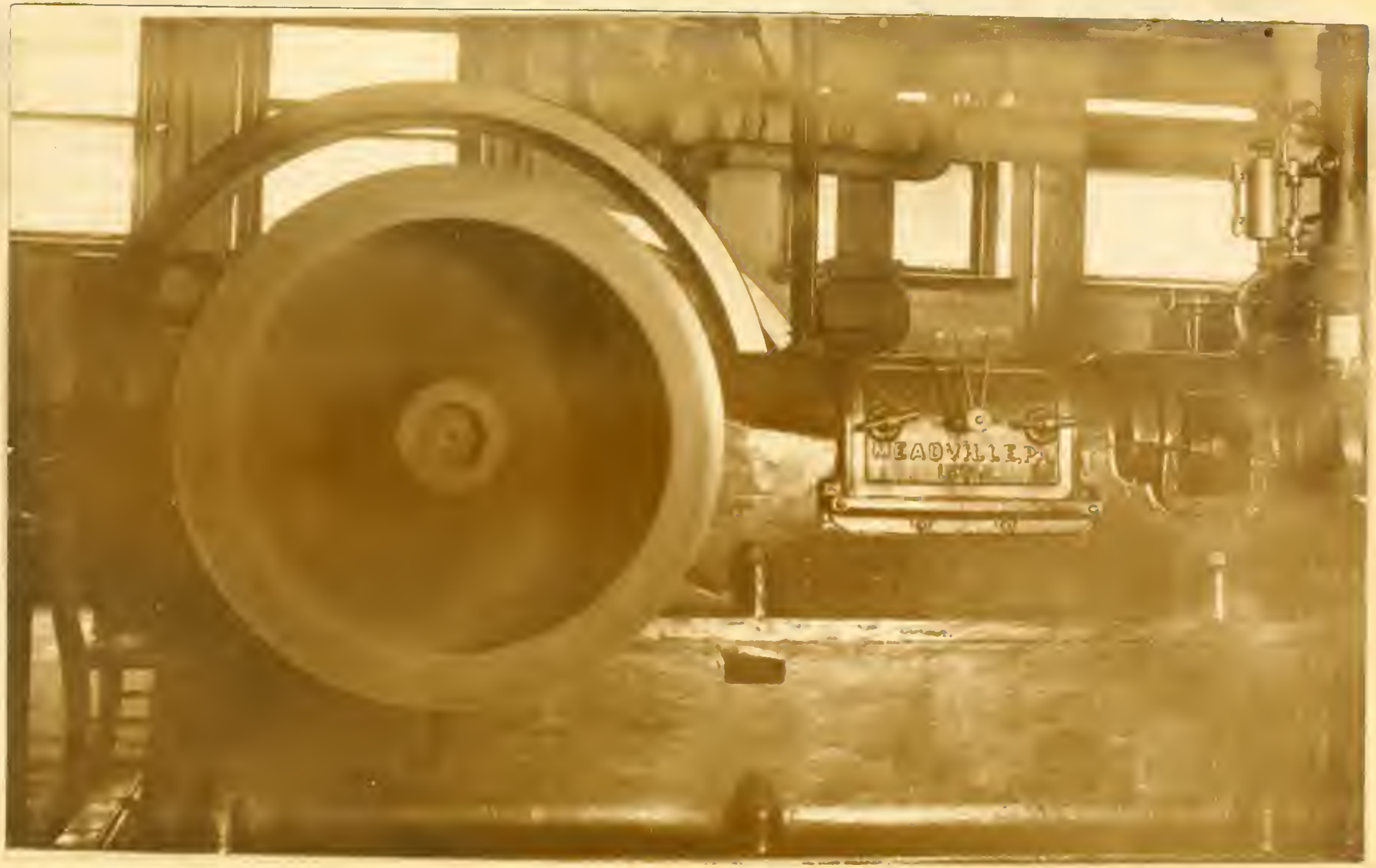


FIGURE 5.

upon the pulley wheel. The reducing motion for the indicators was adjusted and the indicators put in place.

The apparatus was now set up as shown in figure 2. The condenser pump was started and the condensing water was regulated for the required amount to condense the steam. The drips and all the valves in the exhaust line were opened before the engine was started. After the engine had been started the required load was applied; the drips closed; and the lubricators properly adjusted. The steam and exhaust pressures were now adjusted and a series of runs of 30 minute duration were made. The tests were always started after the engine had been running for at least an hour so that conditions were constant.

The following observations were made every 5 minutes during each run:

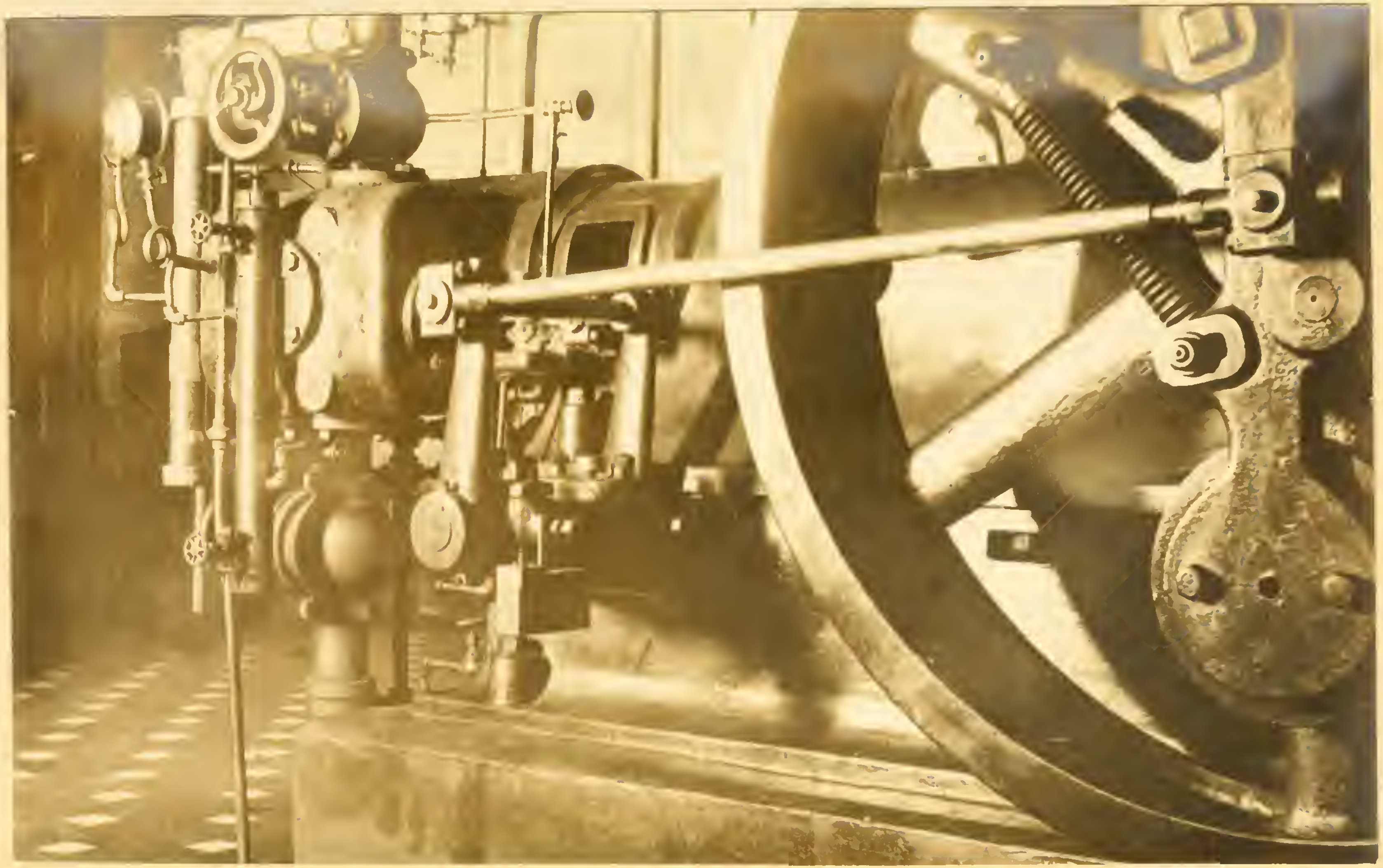


FIGURE 6.

Steam pressure at engine,
Exhaust pressure at engine,
Temperature of the engine room,
Temperature in the calorimeter,
Barometer,
Speed of engine in revolutions per min.,
Load on scales,
Indicator cards from both ends of the cylinder,
Final reading of condensed steam at the end of each run.

DATA AND CALCULATIONS:

Taken from Log Sheet No. 5, test No. 4.

Time, minutes	30
Steam pressure, lbs./sq.in., gauge,	80
Exhaust " " " " "	10"vac.
Revolutions per minute,	300
Load on scales, lbs.,	120
Dead load on scales, lbs.,	19.2
Net " " " "	100.8
Calorimeter temperature, Deg.F.,	255.3
Weight of cond. steam, lbs.,	880.0
" " " " per hr., lbs.,	1760
Room temperature, Deg.F.,	102
Barometer, ins. of Hg.	29.84

Scale of springs, lbs., 60

DATA TAKEN FROM INDICATOR CARDS:

HEAD END.

	Area	Length	M.E.P.	I.H.P.
	2.50	3,88		
	2.86	3.88		
	2.40	3.90		
	2.52	3.90		
	2.10	3.86		
Av.	2.48	3.884	38.2	16.41

CRANK END.

	3.00	3.76		
	3.25	3.76		
	2.95	3.76		
	2.97	3.78		
	2.74	3.78		
Av.	2.982	3.77	47.7	19.8

Total I.H.P. = 19.8 + 16.41 = 36.21

Brake Horse power = $\frac{2\pi L N W}{33000}$

where,

L is the length of brake arm in feet

N is the number of Rev. per minute

W is the net load on the scales.

$$B.H.P. = \frac{2\pi (5.25)\ (300)(100.8)}{33000} = 30.10$$

Mechanical efficiency = $\frac{30.10}{36.21}$ x 100% = 83.1%

The I.H.P. was found by the use of the following formula;

$$I.H.P. = \frac{P L A N}{33000}$$

where,

P is the M.E.P. in pounds per sq.in.,

L is the length of stroke is feet,

A is the area of the piston is sq.in.,

N is the number of Rev. per minute.

M.E.P. for the head end = 38.2

L or length of stroke = 10" or $\frac{10'}{12}$

N or Rev. per minute = 300

A or area of piston head in sq.in.,for the head end = 56.75

$$I.H.P. = \frac{(38.2)\ (10)\ (56.75)\ (300)}{(33000)\ (12)}$$

Reducing,

$$I.H.P. = \frac{38.2 \times 56.75}{132} = 16.41$$

The quality of the steam was found by using the Mollier Diagram. The intersection of the two lines; representing the pressure corresponding to the barometer and the line of degrees of superheat; was followed straight across the diagram where it crossed the line corresponding to absolute steam pressure. The quality was found directly from the latter point.

The weight of dry steam condensed per hour was found by multiplying the weight of wet steam per hour by the quality. The steam used per I.H.P. per hour was found by dividing the weight of dry steam per hour by the I.H.P.

LOG SHEET NO. 1.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests, min.,	30	30	30	30
Barometer, ins. Hg.,	29.64	29.7	29.78	29.7
Room temp. Deg. F.,	100	92	92	90
Steam press. # /Sq. in.,	80	80	80	79.55
Exhaust " " " "	3 inch Vacuum			
Temp. calorimeter, Deg. F.	263	247	263	253
Revolutions per min.,	300	300	300	300
Gross wt. on scales, lbs.	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt. of cond. Steam, lbs.,	362	610	777	972
" " " " lbs./hr.	724	1220	1554	1944
Scale of Springs, lbs.,	60	60	60	60
I.H.P. Crank End,	2.482	7.7	13.6	19.0
I.H.P. Head End,	0.519	6.48	11.32	16.55
Total I.H.P.,	3.001	14.18	24.92	35.55
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P. Crank End,	5.98	18.55	32.70	45.75
M.E.P. Head End,	1.205	15.10	26.52	38.4
Diam. of Cylinder, ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency, %	0	86.4	85.4	82.4
Quality of Steam, %	98.6	97.95	98.8	97.2
Steam/I.H.P./hr. dry,	238	84.8	61.7	53.2
Wt. of dry Steam/hr.,	714	1195	1535	1890
Length of stroke, ins.,	10	10	10	10

Area of piston, Head End, 56.75 Sq. in., C.E. 54.83

LOG SHEET NO. 2A.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.64	29.76	29.7	29.83
Room temp.Deg. F.,	100	96	90	91
Steam press.# /Sq.in.,	85	85	85.5	85
Exhaust " " " "	5 inch Vacuum			
Temp.calorimeter,Deg. F.,	264.33	258.3	257.3	223.1
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam, lbs.,	357	663	800	939
" " " " lbs./hr.,	714	1326	1600	1878
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	2.82	8.01	13.45	17.1
I.H.P.Head End,	0.3545	7.70	12.20	18.5
Total I.H.P.,	3.1745	15.71	25.65	35.6
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	6.8	19.50	32.4	41.2
M.E.P.Head End,	0.825	17.90	28.39	43.0
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	77.95	82.8	84.6
Quality of steam,%	98.8	98.3	98.3	96.7
Steam/I.H.P./hr.dry,	222.1	83.0	61.8	51.3
Wt. of dry steam/hr.,	705	1303	1583	1823
Length of stroke, ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E. 54.83

LOG SHEET NO. 3.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.23	29.74	29.74	29.7
Room temp.Deg. F.,	92	92	90	92
Steam press.# /Sq.in.,	75	75	75	75.5
Exhaust " " " "	5"Vac.	3" Vacuum		
Temp.calorimeter,Deg.F.	259.2	252	256	251.3
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt. of cond.steam,lbs.,	390	600	722	865
" " " " lbs./hr.	780	1200	1444	1730
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	2.295	6.83	12.55	16.80
I.H.P.Head End,	0.391	7.56	11.74	16.59
Total I.H.P.,	2.686	14.39	24.29	33.39
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P. Crank End,	5.54	16.45	28.2	40.45
M.E.P.Head End,	0.910	17.61	27.1	38.45
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	85.0	87.5	90.2
Quality of steam,%	98.7	98.3	98.6	98.3
Steam/I.H.P./hr.dry,	286.6	82.3	58.7	51.0
Wt.of dry steam/hr.,	770	1180	1425	1700
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E. 54.83

LOG SHEET NO. 4.

Tests.	No. 1	No. 2	No. 3	No. 4
Duration of test,min.,		30	30	30
Barometer,ins. Hg.,		29.78	29.78	29.84
Room temp.Deg.F.,		92	92	102
Steam press.# / Sq.in.,		90	90	90
Exhaust " " " "		0	0	0
Temp.calorimeter,Deg.F.,		256.6	257.3	261
Revolutions per min.,		300	300	300
Gross wt.on scales,lbs.,		60	90	120
Tare wt. " " "		19.2	19.2	19.2
Net wt. " " "		40.8	70.8	100.8
Wt.of cond.Steam,lbs.,		687	803	954
" " " " lbs./hr.,		1374	1606	1908
Scale of Springs,lbs.,		60	60	60
I.H.P.Crank End,		9.26	14.0	19.2
I.H.P.Head End,		5.72	11.12	16.02
Total I.H.P.,		14.98	25.12	35.22
Brake Horse Power,		12.23	21.25	30.10
M.E.P.Crank End,		22.35	33.80	45.8
M.E.P.Head End,		15.51	25.90	37.35
Diam.of Cylinder,ins.,		8.5	8.5	8.5
Brake Arm, feet,		5.25	5.25	5.25
Mechanical Efficiency,%		81.7	84.6	85.5
Quality of Steam,%		98.0	98.2	98.3
Steam/I.H.P./hr.dry,		90.0	62.8	53.2
Length of stroke,ins.,		10	10	10
Wt.of dry Steam per hr.,		1348	1577	1875

Area of piston,Head End,56.75 Sq.in.,C.E.54.83

LOG SHEET NO. 5.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of test,min.,	30	30	30	30
Barometer,ins.Hg.,	29.64	29.84	29.84	29.84
Room temp.Deg.F.,	100	102	102	102
Steam press.# /Sq.in.,	80	80	80	80
Exhaust " " " "	10 inch Vacuum			
Temp.calorimeter,Deg.F.,	266.8	255	252	255.3
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	312	641	700	880
" " " " lbs./hr.,	624	1282	1400	1760
Scale of Springs, lbs.,	60	60	60	60
I.H.P.Crank End,	2.11	9.72	13.19	19.80
I.H.P.Head End,	0.522	6.97	10.52	16.41
Total I.H.P.,	2.632	16.69	23.71	36.21
Brake Horse Power,	0.	12.23	21.25	30.10
M.E.P.Crank End,	5.08	23.4	31.8	47.70
M.E.P.Head End,	1.212	16.22	24.95	38.20
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	73.5	89.80	83.10
Quality of Steam,%	98.9	98.4	98.0	98.4
Steam/I.H.P./hr.dry,	234.2	75.5	59.35	47.80
Wt.of dry Steam per hr.,	617	1261	1372	1740
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E.54.83

LOG SHEET NO. 6A.

TESTS.	No. 1	No. 2	No. 3	No.4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.64	29.83	31.26	29.83
Room temp.Deg.F.,	100	91	91	91
Steam press.# /Sq.in.,	85	85	85	85
Exhaust " " " "	10 inch Vacuum			
Temp.calorimeter,Deg.F.	263	259.1	256.6	238.3
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.steam,lbs.,	350	665	770	802
" " " " lbs./hr.,	700	1330	1540	1604
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.01	7.28	13.30	19.21
I.H.P.Head End,	0.142	7.025	11.80	16.80
Total I.H.P.,	3.152	14.305	25.18	36.01
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	7.26	17.52	31.96	46.40
M.E.P.Head End,	0.33	16.33	27.60	39.10
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	85.5	84.5	83.5
Quality of Steam,%	98.7	98.3	98.28	97.2
Steam/I.H.P./hr.dry,	217.3	81.5	60.0	43.30
Wt.of dry Steam per hr.,	685	1307	1515	1560
Length of stroke,ins.,	10	10	10	10
Area of piston,Head End,	56.75 Sq.in., C.E. 54.83/			

LOG SHEET NO.7.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer, ins. Hg.,	29.23	29.5	29.5	29.5
Room temp.Deg. F.,	92	100	96	94
Steam press.# /Sq.in.,	75	75	75	75
Exhaust " " " "	10 inch Vacuum			
Temp.calorimeter,Deg.F.,	254.7	262.66	257.1	258
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	465	608	736	904
" " " " lbs./hr.,	930	1216	1472	1744
Scale of Springs, lbs.,	60	60	60	60
I.H.P.Crank End,	2.75	8.05	12.42	16.68
I.H.P.Head End,	0.456	7.52	12.10	17.50
Total I. H. P.,	3.206	15.57	24.52	34.18
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	6.64	19.42	30.00	40.30
M.E.P.Head End,	1.06	17.45	28.18	40.75
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, Feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	78.6	86.8	88.2
Quality of Steam,%	98.5	98.85	98.6	98.7
Steam/I.H.P./hr.dry,	286.2	72.2	59.20	50.3
Wt.of dry Steam per hr.,	916	1200	1450	1720
Length of stroke,ins.,	10	10	10	10
Area of piston,Head End,	56.75 Sq.in.,C.E.54.83			

LOG SHEET NO. 8.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins.Hg.,	29.23	29.68	29.68	29.68
Room temp.Deg. F.,	92	91	91	91
Steam press.# / Sq.in.,	75	75	75	75
Exhaust " " " " "	0	0	0	0
Temp.calorimeter,Deg.F.	251.6	256	257	257
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	420	643	778	940
" " " " lbs./hr.,	840	1286	1556	1880
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	2.842	9.47	13.00	18.03
I.H.P.Head End,	0.1695	7.89	12.00	17.40
Total I.H.P.,	3.0115	17.36	25.00	35.43
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	6.85	22.81	31.28	43.42
M.E.P.Head End,	0.394	18.36	27.90	40.46
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	70.44	85.00	85.00
Quality of Steam,%	98	98.6	98.6	98.6
Steam /I.H.P./hr.dry,	288.0	72.97	61.0	52.3
Wt.of dry Steam per hr.	823	1268	1524.2	1853.7
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E.54.83

LOG SHEET NO. 9.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests, min.,	30	30	30	30
Barometer, ins. Hg.,	29.23	29.92	29.92	29.92
Room temp. Deg. F.,	92	92	92	92
Steam press. # /Sq. in.,	75	75	75	75
Exhaust " " " "	5 Lbs. back pressure			
Temp. calorimeter, Deg. F.	261	255.43	262	261
Revolutions per min.,	300	300	300	300
Gross wt. on scales, lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt. of cond. Steam, lbs.,	416	647	829	1002
" " " " lbs./hr.,	832	1294	1658	2004
Scale of Springs, lbs.,	60	60	60	60
I.H.P. Crank End,	0.398	7.40	12,50	17.95
I.H.P. Head End,	2.435	7.07	11.88	18.30
Total I.H.P.,	2.833	14.47	24.38	36.25
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P. Crank End,	5.84	17.82	30.15	43.30
M.E.P. Head End,	0.925	16.45	27.60	42.55
Diam. of Cylinder, ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency, %	0	84.60	87.30	83.00
Quality of Steam, %	99	98.5	98.8	98.8
Steam/I.H.P/hr. dry,	291	88.3	67.3	54.50
Steam per hr., lbs. dry,	824	1275	1638	1975
Length of stroke, ins.,	10	10	10	10
Area of Piston, Head End,	56.75 Sq.in., C.E. 54.83			

LOG SHEET NO. 10.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.64	29.92	29.92	29.92
Room temp.Deg. F.,	100	92	92	92
Steam press.# /Sq.in.,	80	80	80	80
Exhaust " " " "	0	0	0	0
Temp.calorimeter,Deg.F.,	266.66	256	259.6	256
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	422	647	792	946
" " " " lbs./hr.,	844	1294	1584	1892
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.1416	9.44	13.88	16.80
I.H.P.Head End,	0.324	7.25	12.65	17.59
Total I.H.P.,	3.4656	16.69	26.53	34.49
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	7.58	22.75	33.40	40.45
M.E.P.Head End,	0.754	16.85	29.42	40.85
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	73.4	80.3	87.6
Quality of Steam,%	99.0	98.3	98.4	98.3
Steam/I.H.P./hr.dry,	240.3	76.3	58.80	55.8
Wt. of dry steam/hr.,	835	1272	1559	1860
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E. 54.83

LOG SHEET NO. 11.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of test,min.,	30	30	30	30
Barometer,ins. Hg.,	29.8	29.26	29.26	29.26
Room temp.Deg. F.,	97	98	98	98
Steam press.# /Sq.in.,	85	85	85	85
Exhaust " " " "	0	0	0	0
Temp.calorimeter,Deg.F.,	262	263.7	263.7	268
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	453	632	811	882
" " " " lbs./hr.,	906	1264	1622	1764
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.87	8.73	11.75	15.85
I.H.P.Head End,	0.1242	5.94	11.10	17.40
Total I.H.P.,	3.994	14.67	22.85	33.25
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	9.31	21.05	28.30	38.20
M.E.P.Head End,	0.288	13.80	25.80	40.50
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	83.5	93.0	90.5
Quality of Steam, %	98.6	98.8	98.8	99.0
Steam/I.H.P./hr.dry,	223.0	85.3	70.2	52.3
Wt. of dry steam/hr.,	893	1250	1605	1748
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E.54.83

LOG SHEET NO. 12.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.39	29.52	29.52	29.52
Room temp.Deg. F.,	92	104	104	104
Steam press.# /Sq.in.,	80	80	80	80
Exhaust " " " "	5 Lbs. back pressure			
Temp.calorimeter,Deg.F.	259	272.3	266.5	0
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.steam,lbs.,	438	656	803	1008
" " " " lbs./hr.	876	1312	1606	2016
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.3	8.97	11.75	16.42
I.H.P.Head End,	0.277	7.33	12.30	19.15
Total I.H.P.,	3.577	16.30	25.05	35.57
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	7.95	21.63	28.30	39.6
M.E.P.Head End,	0.643	16.92	28.60	44.5
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	75.0	88.5	84.8
Quality of Steam,%	98.8	99.4	98.9	99.0
Steam/I.H.P./hr.dry,	242.4	80.1	66.0	56.2
Wt.of dry steam per hr.	866	1305	1588	1995
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E.54.83

LOG SHEET NO. 13.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests, min.,	30	30	30	30
Barometer, ins. Hg.,	29.8	29.01	29.01	29.01
Room temp. Deg. F.,	97	98	98	98
Steam press. # / Sq. in.,	80	80	80	80
Exhaust " " " "	10 Lbs. back pressure			
Temp. calorimeter, Deg. F.	258.5	262.6	266	261.5
Revolutions per minute,	300	300	300	300
Gross wt. on scales, lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt. of cond. steam, lbs.,	483	737	883	1038
" " " " lbs./hr.,	966	1474	1776	2076
Scale of Springs, lbs.,	60	60	60	60
I.H.P. Crank End,	3.37	8.12	12.3	16.18
I.H.P. Head End,	0.492	8.24	13.6	18.88
Total I.H.P.,	3.862	16.36	25.9	35.06
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P. Crank End,	7.87	19.54	29.70	39.00
M.E.P. Head End,	1.142	19.00	31.64	43.90
Diam. of Cylinder, ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency, %	0	75.0	82.10	86.0
Quality of Steam, %	98.6	98.8	99.0	98.7
Steam/I.H.P./hr. dry,	246.5	89	65.45	58.4
Wt. of dry Steam per hr.,	954	1458	1760	2045
Length of stroke, ins.,	10	10	10	10
Area of piston, Head End,	56.75 Sq.in., C.E. 54.83			

LOG SHEET NO. 14.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of test,min.,	30	30	30	30
Barometer,ins. Hg.,	29.8	29.01	29.01	29.46
Room temp.Deg.F.,	97	98	98	92
Steam press.# /Sq.in.,	85	85	85	85
Exhaust " " " "	10 Lbs. back pressure			
Temp.calorimeter,Deg.F.,	262	266	265.4	260.6
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	437	740	853	1029
" " " " lbs./hr.,	874	1480	1706	2058
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.36	7.89	12.10	18.31
I.H.P.Head End,	0.245	8.36	13.15	17.20
Total I.H.P.,	3.605	16.25	25.25	35.51
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	8.1	19.0	32.25	44.2
M.E.P.Head End,	0.569	19.45	30.60	40.2
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	75.3	84.25	85.0
Quality of Steam,%	98.6	99.1	99.0	98.5
Steam/I.H.P./hr.dry,	239	90.3	67.0	57.3
Wt.of dry Steam per hr.,	862	1468	1690	2030
Length of stroke,ins.,	10	10	10	10
Area of piston,Head End,	56.75 Sq.in.,C.E.54.83			

LOG SHEET NO. 15.

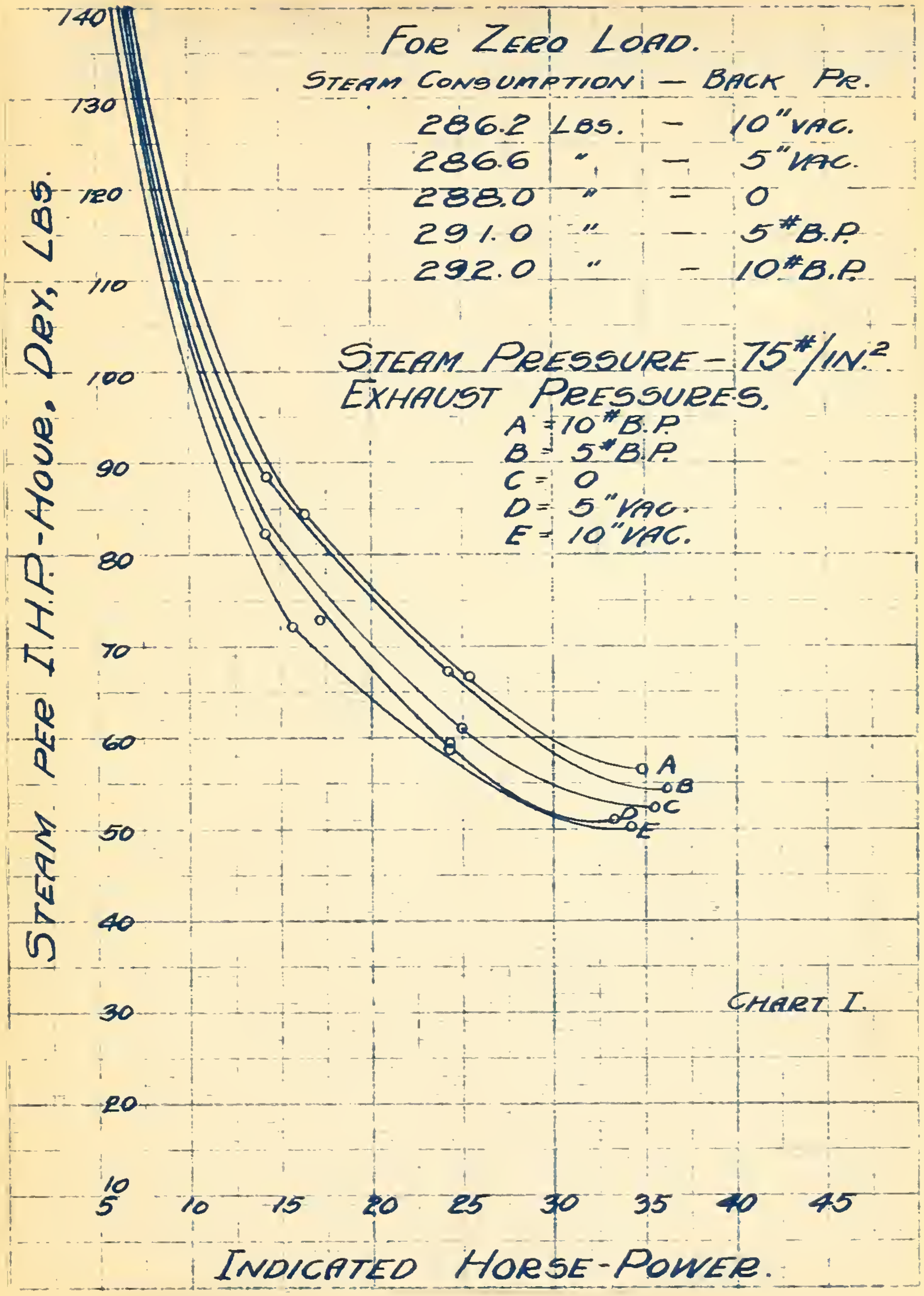
TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.,	29.8	29.17	29.17	29.17
Room temp.Deg. F.,	97	93	93	93
Steam press.# /Sq.in.,	85	85	85	85
Exhaust " " " "	5 Lbs. back pressure			
Temp.calorimeter,Deg.F.,	261.6	263	261.2	260
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.,	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	458	720	833	958
" " " "lbs./hr.,	916	1440	1666	1916
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.98	8.32	12.04	16.28
I.H.P.Head End,	0.0775	7.70	13.20	18.65
Total I.H.P.,	4.0575	16.02	25.24	34.93
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	9.6	21.05	29.0	39.20
M.E.P.Head End,	0.180	17.92	31.25	43.30
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	76.45	84.2	86.2
Quality of steam,%	98.6	98.80	98.50	98.3
Steam/I.H.P./hr.dry,	223.2	88.80	65.0	54.0
Wt.of dry steam/hr.,	904	1420	1640	1886
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E. 54.83

LOG SHEET NO. 16.

TESTS.	No. 1	No. 2	No. 3	No. 4
Duration of tests,min.,	30	30	30	30
Barometer,ins. Hg.	29.23	29.46	29.46	29.46
Room temp.Deg. F.,	92	92	92	92
Steam press.# / Sq.in.,	75	75	75	75
Exhaust " " " " "	10 Lbs. back pressure			
Temp.calorimeter,Deg.F.	264.3	258.5	260	262
Revolutions per min.,	300	300	300	300
Gross wt.on scales,lbs.	0	60	90	120
Tare wt. " " "	0	19.2	19.2	19.2
Net wt. " " "	0	40.8	70.8	100.8
Wt.of cond.Steam,lbs.,	460	702	852	1025
" " " " lbs./hr.	1120	1404	1704	2050
Scale of Springs,lbs.,	60	60	60	60
I.H.P.Crank End,	3.182	6.71	11.40	18.11
I.H.P.Head End,	0.628	9.76	13.88	16.82
Total I.H.P.,	3.810	16.47	25.28	34.93
Brake Horse Power,	0	12.23	21.25	30.10
M.E.P.Crank End,	7.67	23.6	33.50	43.80
M.E.P.Head End,	1.46	15.6	26.55	39.10
Diam.of Cylinder,ins.,	8.5	8.5	8.5	8.5
Brake Arm, feet,	5.25	5.25	5.25	5.25
Mechanical Efficiency,%	0	74.3	80.2	86.3
Quality of Steam,%	99.1	98.3	98.5	98.6
Steam/I.H.P./hr.dry.,	292.0	84.0	66.5	56.8
Wt.of dry Steam per hr.	1110	1380	1680	1980
Length of stroke,ins.,	10	10	10	10

Area of piston,Head End,56.75 Sq.in.,C.E.54.83


For Zero Load.
Steam Consumption — Back Pr.
286.2 Lbs. — 10" vac.
286.6 " — 5" vac.
288.0 " — 0
291.0 " — 5# B.P.
292.0 " — 10# B.P.
Steam Pressure — 75#/in.²
Exhaust Pressures.
A = 10# B.P.
B = 5# B.P.
C = 0
D = 5" vac.
E = 10" vac.
A
B
C
D
E
Steam per I.H.P.-Hour, Dry, Lbs.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
Indicated Horse-Power.
Chart I.

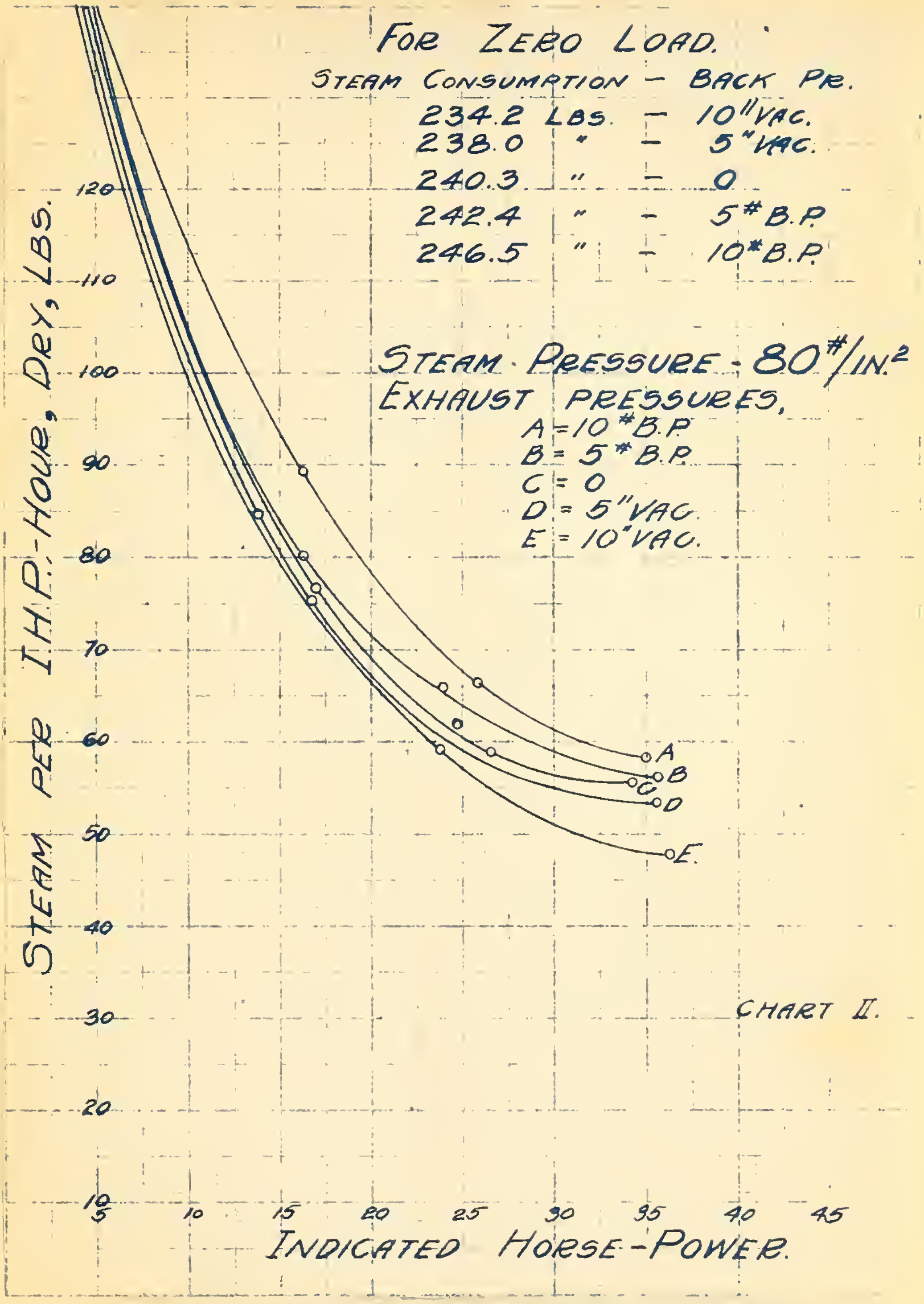

For Zero Load.
Steam Consumption – Back Pr.
234.2 Lbs. – 10" Vac.
238.0 " – 5" Vac.
240.3 " – 0
242.4 " – 5# B.P.
246.5 " – 10# B.P.
Steam Pressure – 80#/in.²
Exhaust pressures,
A = 10# B.P.
B = 5# B.P.
C = 0
D = 5" Vac.
E = 10" Vac.
A
B
C
D
E.
Steam per I.H.P.-Hour, Dry, Lbs.
120
110
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
35
40
45
Indicated Horse-Power.

Chart II.

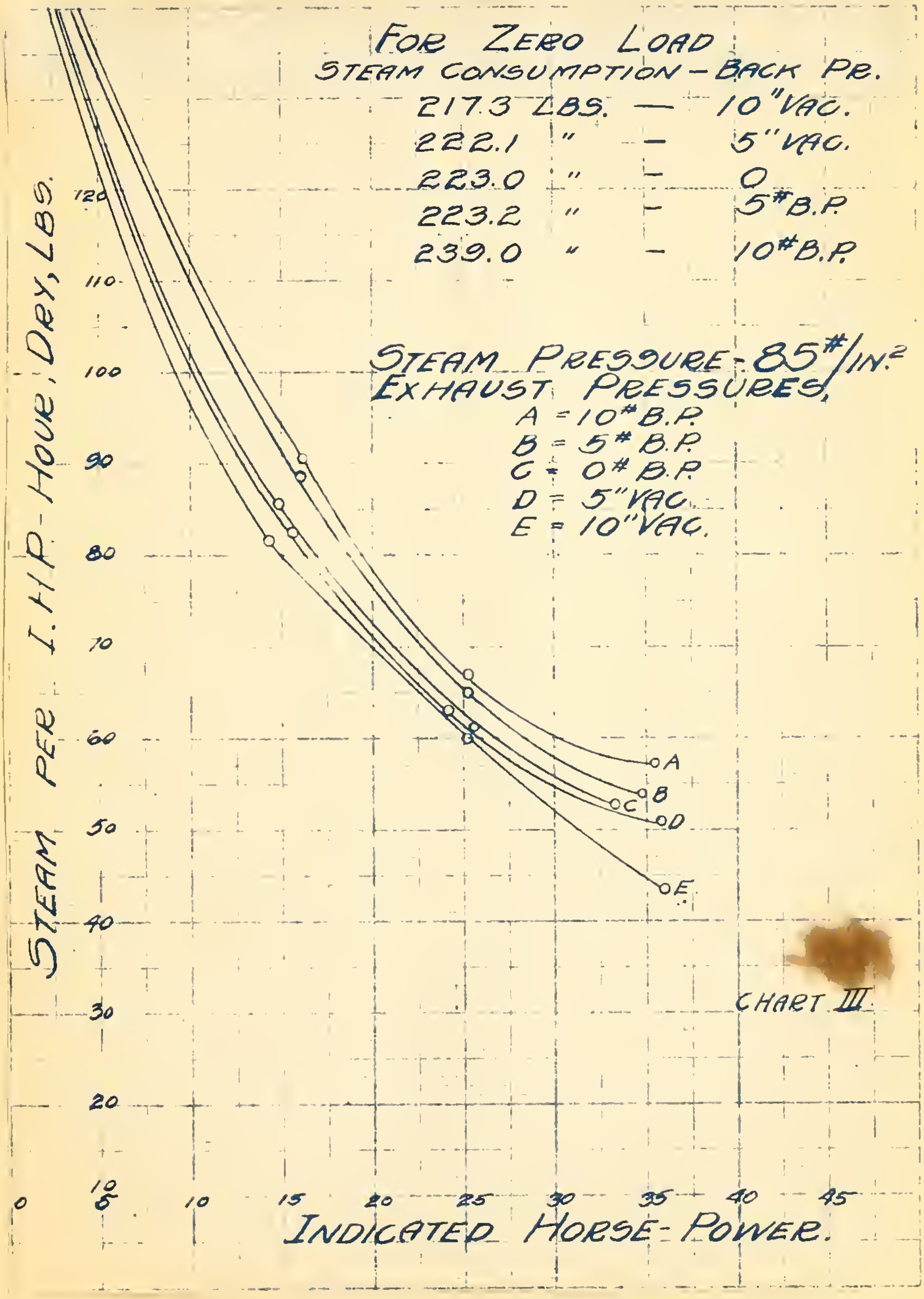

FOR ZERO LOAD
STEAM CONSUMPTION — BACK PR.
217.3 LBS. — 10" VAC.
222.1 " — 5" VAC.
223.0 " — 0
223.2 " — 5# B.P.
239.0 " — 10# B.P.
STEAM PRESSURE - 85#/IN.²
EXHAUST PRESSURES,
A = 10# B.P.
B = 5# B.P.
C = 0# B.P.
D = 5" VAC.
E = 10" VAC.
A
B
C
D
E
STEAM PER I.H.P.-HOUR, DRY, LBS.
120
110
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
INDICATED HORSE-POWER.

CHART III

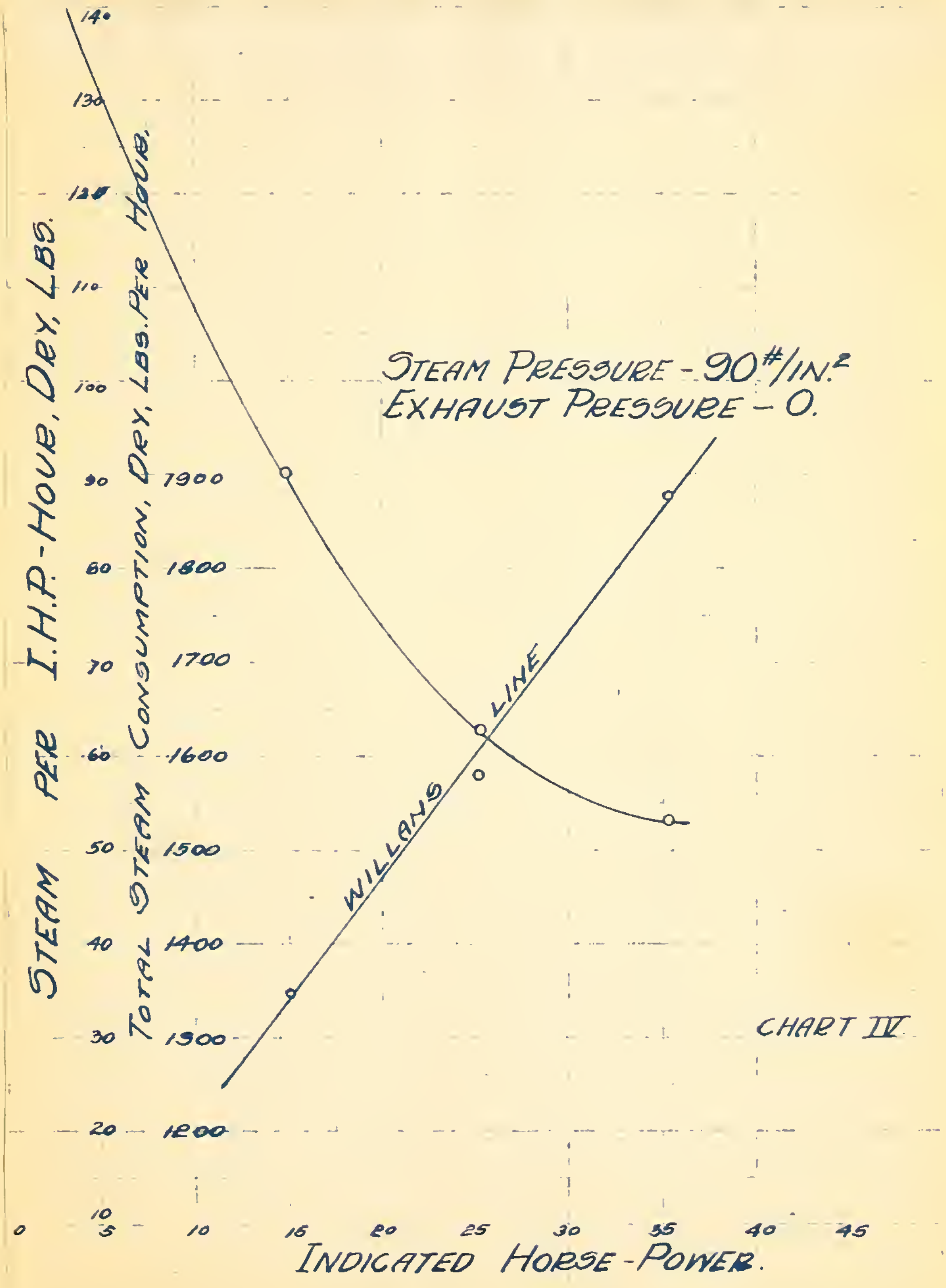
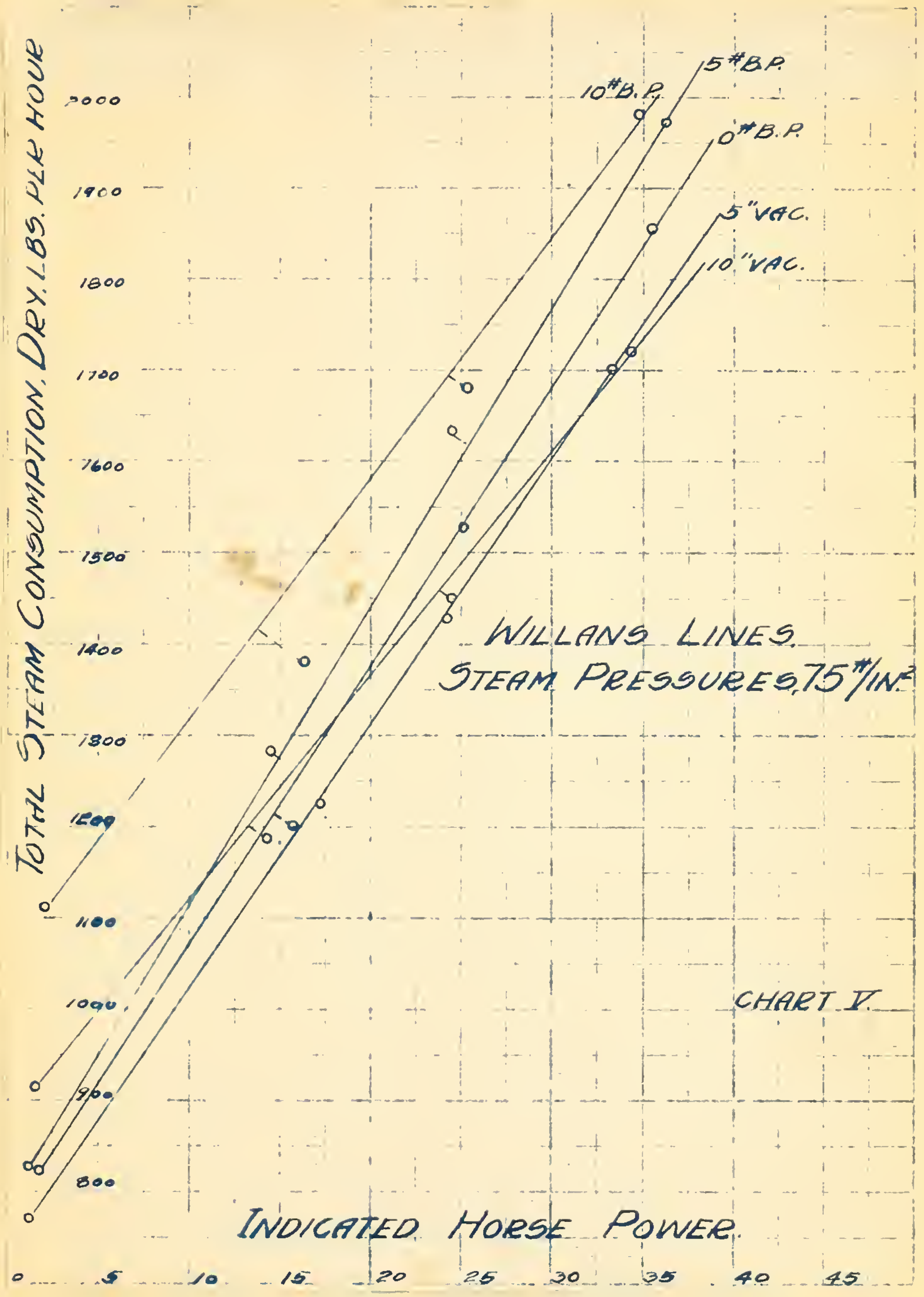
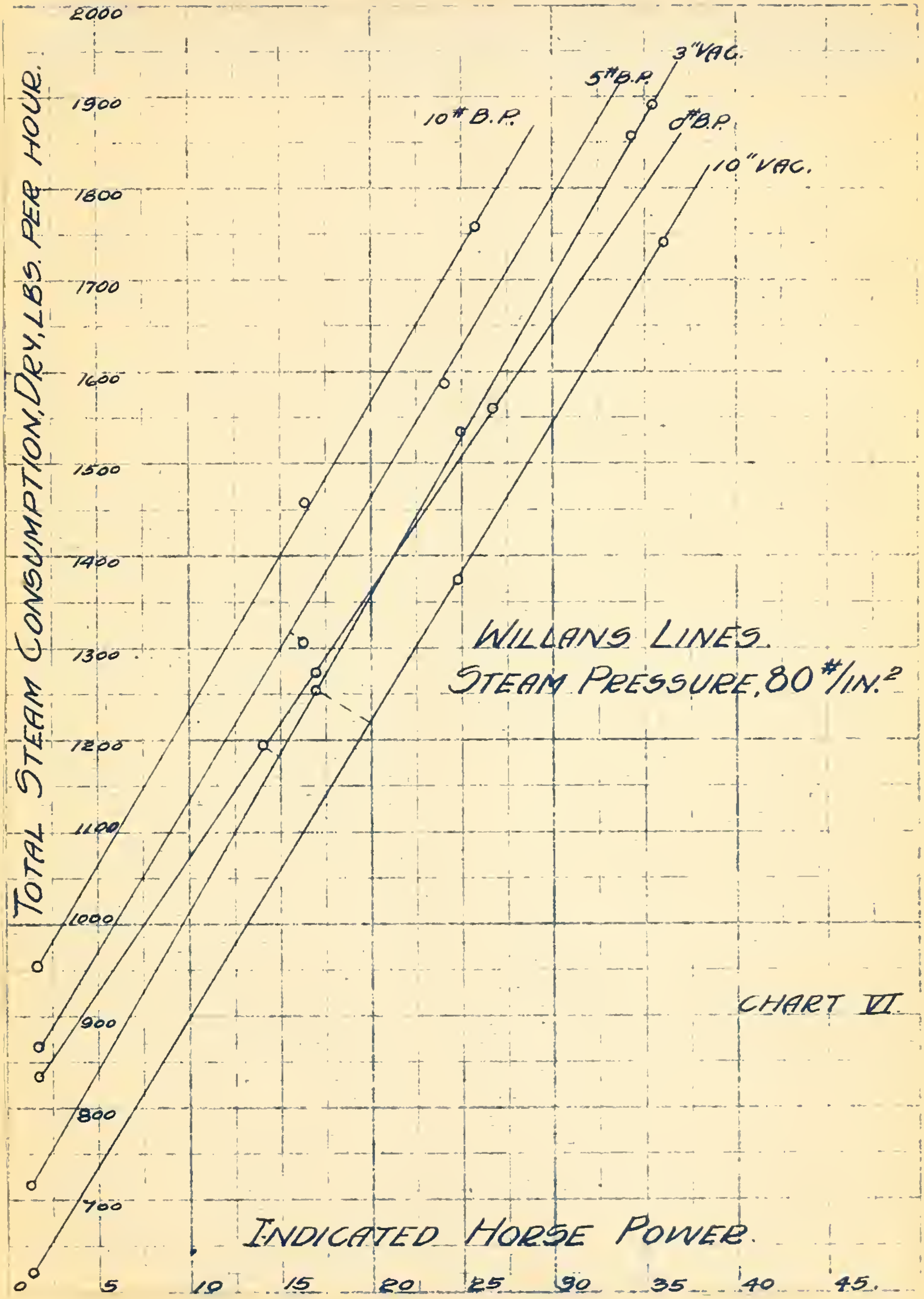

Steam Pressure - 90#/in.²
Exhaust Pressure - 0.
Steam per I.H.P.-Hour, Dry, Lbs.
Total Steam Consumption, Dry, Lbs. per Hour.
Willans Line
140
130
120
110
100
90
80
70
60
50
40
30
20
10
1900
1800
1700
1600
1500
1400
1300
1200
0
5
10
15
20
25
30
35
40
45
Indicated Horse-Power.

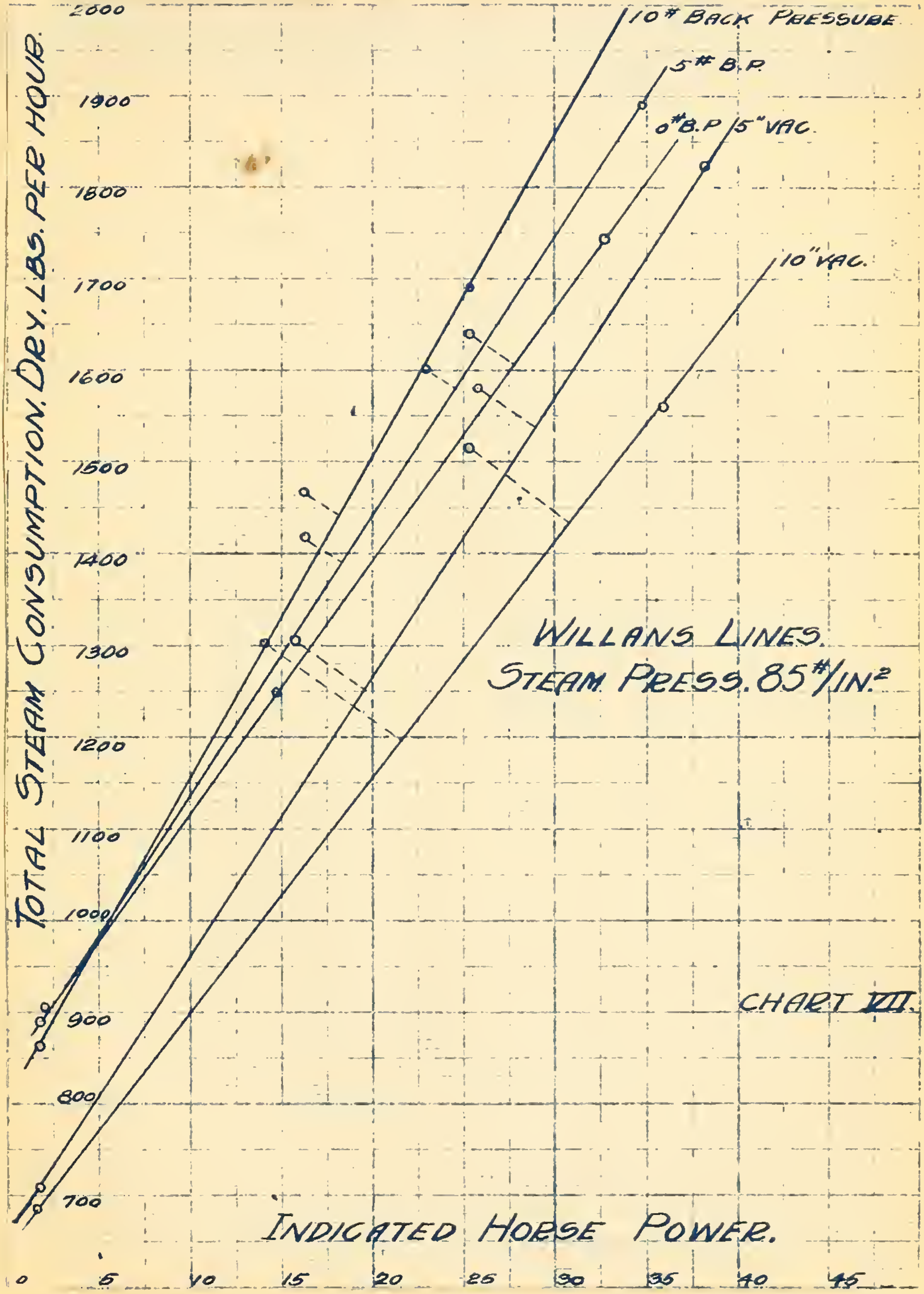
CHART IV.


Total Steam Consumption, Dry. Lbs. per Hour
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
10#B.P.
5#B.P.
0#B.P.
5"VAC.
10"VAC.
Willans Lines.
Steam Pressures, 75#/in.²
Chart V.
Indicated Horse Power
0
5
10
15
20
25
30
35
40
45



Willans Lines.
Steam Pressure, 80#/in.^{2}

Chart VI.


10# Back Pressure
5# B.P.
0# B.P.
5" Vac.
10" Vac.
Willans Lines.
Steam Press. 85#/in.²
Chart VII.
Total Steam Consumption. Dry. Lbs. per Hour.
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
Indicated Horse Power.
0
5
10
15
20
25
30
35
40
45

SUMMARY:

The economy of the Phoenix engine used in this experiment varies directly with the initial and back pressures.

A study made of the curves as shown by charts 1 to 7 inclusive demonstrates clearly that the higher the initial pressures and the lower the back pressures, the higher the efficiency and economy of this engine.

However, it is regretted that higher pressures and lower back pressures than those used in this test were unobtainable. Again, the engine developed, during several important tests, a serious "Knocking" which prevented the continuation of this experiment.

The practical experience and technical knowledge gained throughout the experi-

ment has taught the writer the value of higher initial and lower back pressures. He has also become familiar with the methods of procedure followed in obtaining the efficiencies of reciprocating high speed engines.

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